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REPORT

**CEEFAX:
UHF field trials**

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Summary

Field trials were carried out using experimental CEEFAX data transmissions at the two information rates of 4.5 and 6.875 Mbits/s. The purpose of the trials was to investigate the coverage or service area of CEEFAX in comparison to that of the associated colour television signal and to see if there were any special problems with the transmission and reception of CEEFAX which did not arise with colour television.

The results indicated that CEEFAX was a rugged transmission system and that in general the size of the service area for CEEFAX transmission was greater than that for colour television. There was very little difference in the sizes of the service area for either the low or high data bit-rates.

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Section	Title	Page
	Summary	Title Page
1.	Introduction	1
2.	Transmitted CEEFAX signals	1
3.	Receiving equipment and method of measurement	1
4.	Extent of the survey	3
5.	Results	5
6.	Conclusions	7
7.	References	8
	Appendix I	8
	Appendix II	9

CEEFAX: UHF FIELD TRIALS

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1. Introduction

CEEFAX has been described elsewhere¹ but, briefly, it is a system of data transmission in the form of pulse-code modulated signals carried on two spare lines in the field-blanking interval of otherwise normal 625-line television transmission. A specially adapted receiver can decode the signals and provide pages of information displayed on the normal television screen. CEEFAX has been broadcast experimentally in several forms, all basically similar but with different information rates. The purpose of the field trials was to relate the service area for CEEFAX to that of the associated colour television signal.

As already stated, CEEFAX transmissions use a data signal which has the well-known property of providing perfect, or near-perfect, transmission within the service area until increasing interference sometimes combined with distortion, causes the abrupt onset of incorrect decisions in the decoding equipment. This contrasts with an analogue system such as television, in which the increasing interference merely causes the picture to become progressively degraded. However, since the human eye is extremely adaptable, very poor pictures can be watched and yet still provide the viewer with information and entertainment. This is not the case with CEEFAX; when serious errors start to occur, an increase of only one or two dB in the amount of interference causes reception to break down completely.

The purpose of the field trials was to investigate the CEEFAX service area and to see if, in all practical reception situations, it compared favourably with that of normal colour television. In this way CEEFAX could be transmitted by the existing system of distribution networks and transmitters. This information was then used to assist the Working Group* that was set up to determine the form of the final unified data broadcast system.²

2. Transmitted CEEFAX signals

The CEEFAX data signals were carried by lines 17 (330) and 18 (331) in the television field-blanking period^{3,4} and were added to the video signals in Central Apparatus Room at Television Centre; in consequence they were radiated by all BBC transmitting stations.

NRZ** data-coding had been chosen for CEEFAX⁵ and one of the factors in this choice was the need for a high information rate. The first CEEFAX transmissions¹ took

* Combined Working Group on Data Transmission and Display, under the auspices of The British Radio and Electrical Manufacturers' Association.

** Non-Return-to-Zero.

place using a data-rate of 4.5 Mbits/s, using raised-cosine pulses with a spectrum extending to about 4.5 MHz and the first survey described in this Report was made using these transmissions.

Whilst this first survey was in progress, a proposal was made by the receiver manufacturing industry that the bit-rate should be increased to a value permitting the transmission on one television data-line of sufficient data for one complete row of characters, (together with the necessary addresses). This proposal was made because it would greatly simplify the domestic receiver. There was also the view that the minimum number of characters in each row of the page should be 40, compared with the 32 used in the original CEEFAX system. These two requirements combined to demand a bit-rate close to 7 Mbits/s; this was an attractive and tempting target, leading not only to a simpler and cheaper receiver but also to a faster system. As a result of these proposals, further field trials were carried out and three bit-rates were chosen for this purpose; 4.5 Mbits/s (as first used for CEEFAX), 5.75 Mbits/s and 6.875 Mbits/s. The data format was unchanged for all these tests and, in consequence, at the higher bit-rates, the data signals occupied a smaller proportion of the television lines, on which they were carried; the higher bit-rate transmissions was accordingly described as 'Compressed CEEFAX'. The use of raised-cosine pulses was not possible for the higher bit-rates whose power spectra would otherwise require to extend to 5.75 MHz and 6.875 MHz, respectively. The spectra of these signals were therefore shaped first according to an appropriate raised-cosine law and, secondly truncated at about 4.4 MHz using a linear-phase low-pass filter. The value of 4.4 MHz was chosen to reduce the effects of receiver group-delay distortion, as well as to anticipate the requirements of Systems B and G. Laboratory tests had shown⁵ that this technique was feasible, although it was realised that the spectrum obtained in practice might not be ideal. However, it was thought that, provided satisfactory results were obtained, the performance of any future system was certain to be at least as good, and probably better.

For reasons given later in this Report, the tests on the intermediate data-rate of 5.75 Mbits/s were abandoned at a fairly early stage, and eventually signals on only the 6.875 Mbits/s system were transmitted.

3. Receiving equipment and method of measurement

A mobile laboratory was used for the tests. The vehicle had an independent 240V, 50 Hz motor-generator and an external aerial system ten metres above ground level. The laboratory was equipped internally with a u.h.f. receiver to feed a video signal to a CEEFAX decoder, black-and-white and colour television receivers, and field-strength

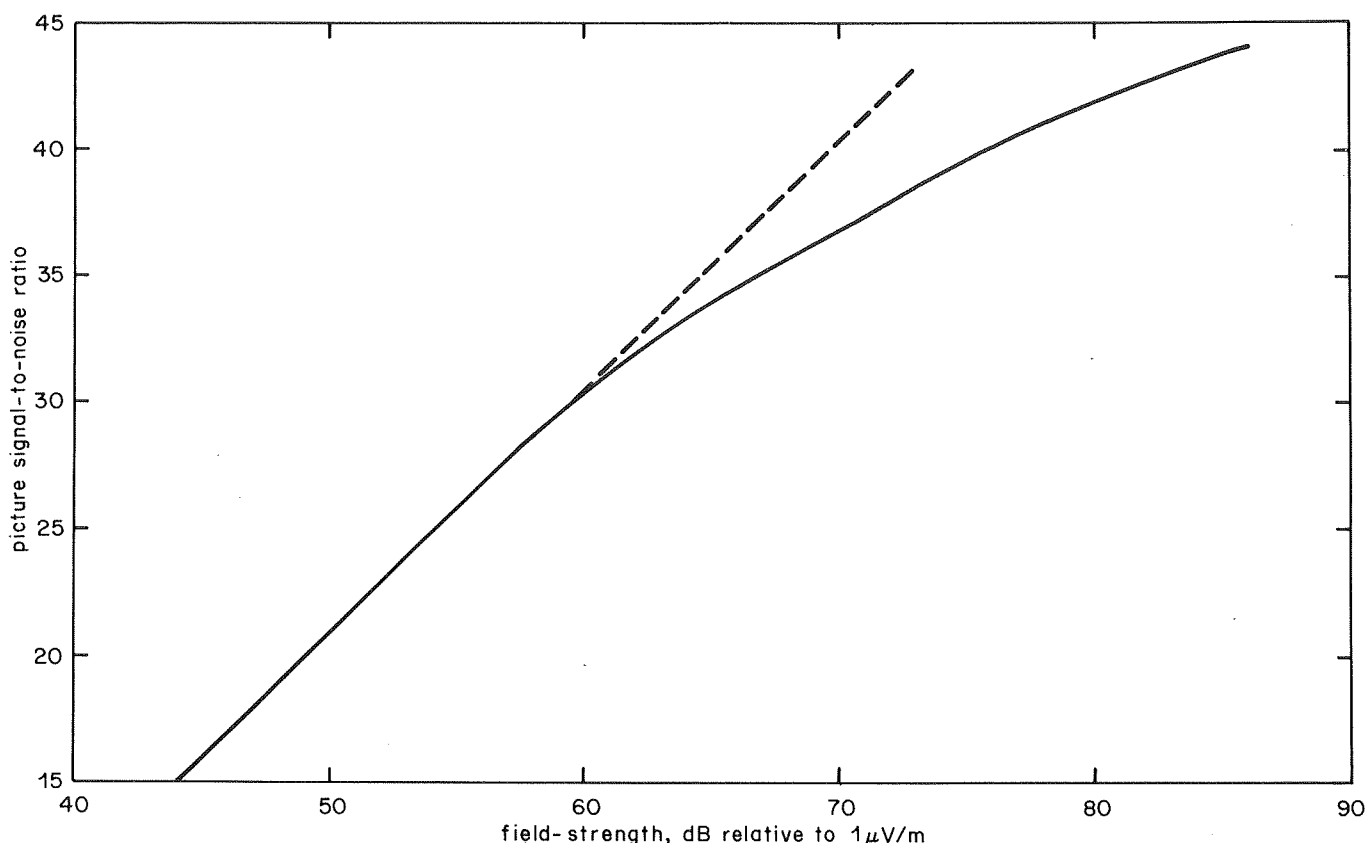


Fig. 1 - Picture signal-to-noise ratio as a function of field-strength measured in the mobile laboratory

measuring equipment. The u.h.f. receiver was of fairly high performance although it used envelope detection and exhibited some variation of group-delay across the pass-band. However, in view of the non-availability of other equipment and the urgent nature of the work, it was felt that, if good results could be obtained with this receiver, then these results could be relied upon in future applications to a domestic broadcasting service.*

Under the advice of Service Planning Section and BBC Engineering Information Department, the aerial system used was equivalent to a typical fringe-area domestic aerial installation. Appendix I gives the details of the installation and Fig. 1 gives the received picture signal-to-noise ratio as a function of field-strength at the aerial. At each receiving site, the first step was to rotate the aerial to give optimum reception of colour television on all three channels; this sometimes involved a compromise because local effects could impair one channel more than the others. Thus, the same adjustments were made as for a normal domestic installation and all the CEEFAX measurements then followed without further adjustment of the aerial. A block diagram of the equipment arrangement in the laboratory is shown in Fig. 2.

* In arriving at a specification for a broadcast data Service, the representatives of receiver manufacturers on the Working Group have recognised the need for a receiver group-delay performance significantly better than is normally required for the domestic reception of colour television. The receiver used in the tests had a performance somewhat inferior to that now envisaged by manufacturers for future domestic data receivers.

The choice of receiving sites is discussed in the next section.

A routine series of tests was performed at each site and the results were recorded on a prepared data sheet; an example of a completed data sheet is shown in Fig. 3. It was important to find out the circumstances under which CEEFAX reception would break-down.* In general, receiver noise due to low field-strength was found to be the most common form of interference, but any other form of interference which could influence the determination by the decoder of the presence or absence of a pulse had the same effect, as also did distortion of the pulse-shape, such as may be caused by group-delay errors and multipath propagation. All forms of interference and distortion can

* Throughout the field trials an arbitrary reference was used to define the failure of CEEFAX reception. This was when only 50% of the data was received correctly on one writing of a page and corresponds to a digital error-rate of approximately $1 \text{ in } 10^2$. This reference is accurate to use in practice because, as is common with data signals, it is sharply defined.

The particular page of CEEFAX data, used in these tests, was the so-called 'clock-cracker' (alternative character codes 11111110;01111111 for entire page) which provides a severe test of clock synchronisation in the decoder and where errors or blanks are easily spotted. It was later found that some other character codes or combinations of characters were more frequently corrupted by interference and the results might be between 1 dB and 2 dB optimistic. However the performance of the CEEFAX decoder, used in these tests, has since been improved in respect of its clock synchronisation by a similar amount. Hence the results of these field-trials should be representative of a complete CEEFAX data service.

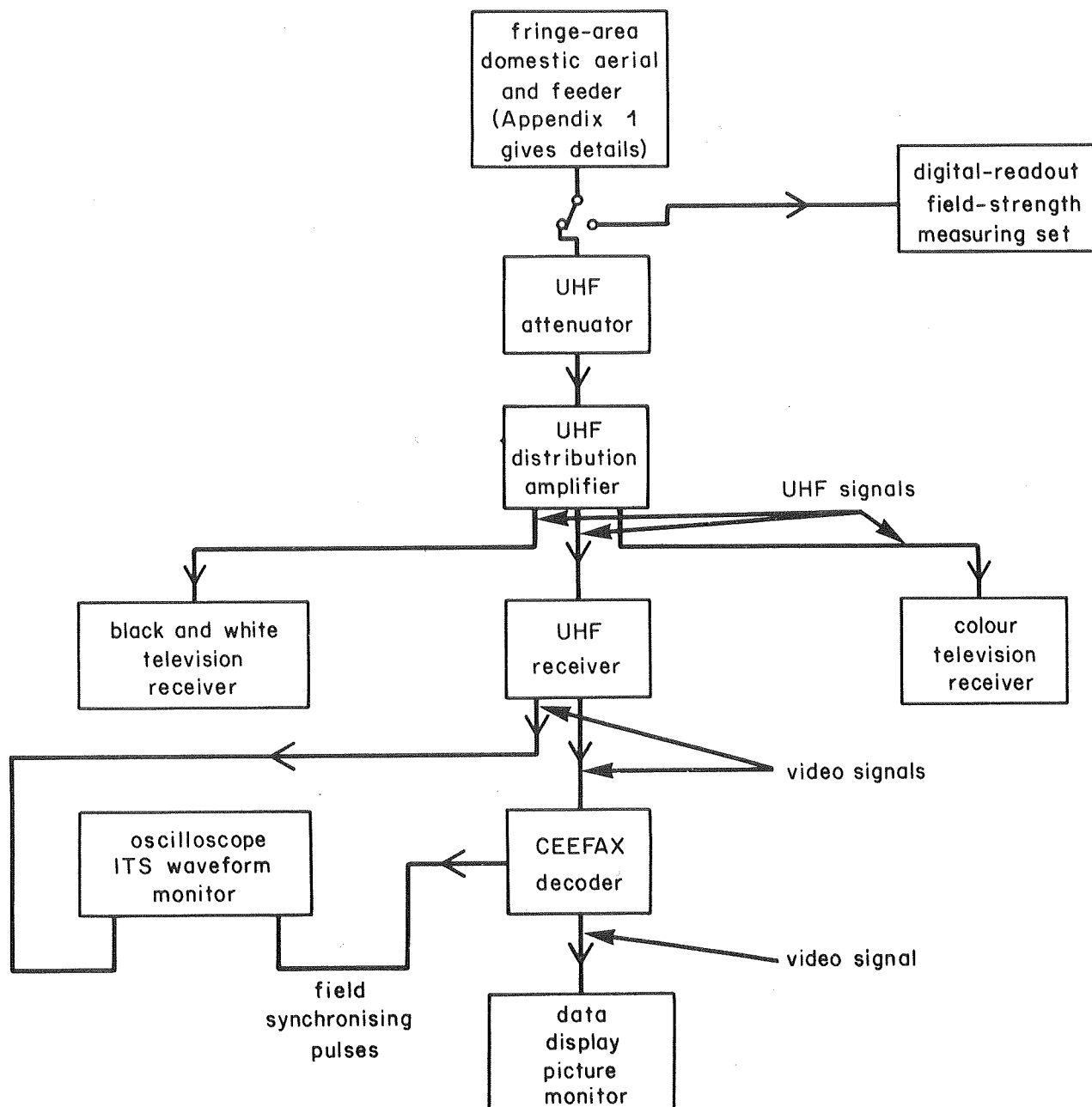


Fig. 2 - Arrangement of equipment in mobile laboratory

act together, and their combined effect is to increase the probability of a decision-error in the decoding process and hence an incorrect, absent, or wrongly-located character on the displayed page. For these reasons, the effects of noise, echoes and other forms of interference were assessed both subjectively, by viewing the picture on the colour television receiver, and objectively by making waveform measurements on an oscilloscope. The field-strength at which CEEFAX reception broke down was also measured at all sites by the following method: first, the field-strength at the site was measured and an attenuator, placed in series with the aerial feed, was adjusted until the limit of reception was reached; the effective field-strength was then determined by subtracting the dB attenuator reading from the previously measured field-strength.

4. Extent of the survey

It was not the purpose of the survey to duplicate the work of the u.h.f. television surveys, but to obtain sufficient information to assess the CEEFAX service areas in comparison with that of the associated colour television signal. It was also important to look for special problems that might arise for CEEFAX which did not arise with television. The survey covered the south-east of England, using signals obtained mainly from the Crystal Palace transmitter. Signals from other transmitters were also used, notably Heathfield and Midhurst, and the relay stations of Reigate, Guildford and Tunbridge Wells.

In the survey, three main types of site were looked

Fig. 3 - Data sheet showing routine series of tests made at each Reception Site

CEEFAX FIELD TRIALS

SITE:						
Date	9. 11. 73	ALDERSHOT	MYTCHETT	FRIMLEY GREEN	BLACKWATER	SANDHURST
Location	JUNCTION OF A3013 and A324		A3013			
Weather Conditions	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	
Type of Site: (Hilly, Flat, Rural, Residential, Industrial, City)	RESIDENTIAL HILLY	RESIDENTIAL HILLY	RESIDENTIAL HILLY	RESIDENTIAL HILLY	RESIDENTIAL HILLY	
Transmitter and Channel No.	C.P.33	C.P.33	C.P.33	C.P.33	C.P.33	
Ease of aerial adjustment to obtain best colour picture†	GOOD	FAIRLY HARD	GOOD	GOOD	GOOD	
Signal level dB (μV)	53	42	54	47	53	
Field Strength dB (μV/m)	63	52	64	57	63	
Video Sig./Noise (dB)	28	17	28	22	28	
† Aerial adjusted for best colour picture and left in this condition for remainder of tests.						
'Ghosts' of the I.T.S. 2T pulse:						
Number visible on CRO	2	NIL	3	2	3	
Level of strongest (V wrt 0.7V)	0.1		0.15	0.1	0.2	
Delay of strongest (μs)	-0.2		-0.2	-0.2	-0.2	
Level of next strongest (V wrt 0.7V)	0.05		0.05	0.05	0.1	
Delay of next strongest (μs)	1		0.2	0.4	0.2	
CEEFAX Displayed Errors (using Page 23) (For three separate sweeps)			CEEFAX LESS THAN 50% 2			
	1	2	3	1	2	3
(i) No. of Address Errors (Blank Rows)	0	0	0	0	0	0
(ii) No. of Character Blanks on whole page (not including blank rows)	0	0	0	0	13	1
(iii) No. of Wrong Characters* (not blank)	0	0	0	0	6	0
(iv) No. of Wrong Rows (from other pages)	0	0	0	0	0	0
* i.e. except those due to (iv)						
dB aerial attenuation to give about 50% errors (one sweep)	7 dB		9 dB	3 dB	8 dB	
Picture Quality (using Colour Receiver):						
Impulsive Noise Interference**	2	1	3	1	3	
Random Noise Interference**	3	5	3	4	2	
Ghost Interference**	3	1	2	2	3	
Overall Quality***	4	5	3	4	3	
Number of Visible 'Ghosts'	3	0	1	2	3	
General Comments e.g. other forms of interference ** EBU Impairment Scale *** EBU Quality Scale	Hannington 65 dB (μV/m) Rowridge 52 dB (μV/m) Local aerials directed towards Hannington	Hannington 73 dB (μV/m) Local aerials directed towards Hannington and Crystal Palace	Hannington 62 dB (μV/m) with 4 ghosts. Local aerials directed towards Hannington and Crystal Palace	Midhurst 46 dB (μV/m) Hannington 68 dB (μV/m) with one ghost Grade 3. Local aerials directed towards Hannington and Crystal Palace	Hannington 69 dB (μV/m) with 3 faint ghosts. Local aerials directed towards Hannington and Crystal Palace	
Engineer						

for; those of low field-strength, those where multipath interference was a problem and those where impulsive interference was likely to be found. To find these sites the mobile laboratory travelled to the outer parts of the Crystal Palace transmitter service area for sites with low field-strength, to Kenley, Caterham Valley and the North-Downs for sites with multipath interference, and to positions of low field-strength by main roads for sites affected by impulsive interference. Two other kinds of site were also tested; the survey vehicle travelled to the centre of London in an effort to find areas where combinations of interference could be found due to the effects of traffic and high buildings, and other sites were sought where co-channel interference would be a problem. Since none could be found, co-channel interference was obtained artificially by mixing signals received from the Tunbridge Wells and Sudbury transmitters. Appendix II gives the details.

The survey was carried out over a period of several months using initially CEEFAX with a bit-rate of 4.5 MBits/s, broadcast using the BBC-2 network. Later trials were then made with data-rates of 4.5 MBits/s, 5.75 MBits/s and 6.875 MBits/s, but the intermediate frequency of 5.75 MBits/s was soon abandoned. The reason was that, as is shown in the next section, there was little difference in the performances of the systems at any of the frequencies and there was therefore no point in investigating

the effects of the intermediate frequency on data reception. At this time BBC-2 transmitters were closed down during the working day and the CEEFAX transmissions were transferred to BBC-1.

5. Results

The results are divided into two main groups: those for the data-rate of 4.5 MBits/s and those for 6.875 MBits/s. Table 1 gives the mean of the results for the five types of site tested. It shows the equivalent field-strength (dB relative to 1 μ V/m) at which reception of CEEFAX was found to break down, and the mean subjective grading of the colour television picture with respect to the type of interference received at each site.

It can be seen that there is little difference (about $\frac{1}{2}$ dB) between the field-strength requirements at either of the two data-rates. At 6.875 MBits/s the field-strength at which CEEFAX reception was found to break down was 56 dB (μ V/m) and this should be compared with 65 dB (μ V/m) which is normally taken as the service limit for colour television reception. There was thus a 9 dB margin in favour of CEEFAX. Since the field trials signals according to the new unified data system have been transmitted.⁵ These have an increased data signal level and a slightly higher data bit-rate of 6.9375 MBits/s and the

TABLE 1

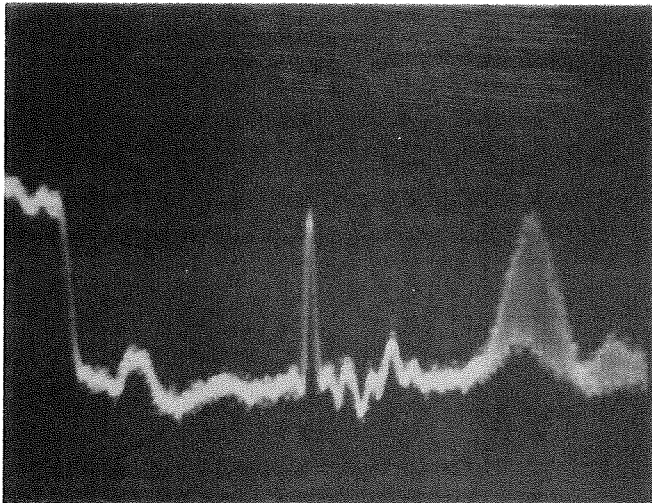
	Number of sites tested		Average field-strength for CEEFAX reception to fail dB(μ V/m)		Mean grade on EBU Impairment Scale* for specified reception impairment	
	4.5 MBits/s	6.875 MBits/s	4.5 MBits/s	6.875 MBits/s	4.5 MBits/s	6.875 MBits/s
Sites with only receiver-noise interference	60	30	55.5	56.0	5.5	5.3
Sites with multipath interference	22	14	60.0	60.5	5.5	5.4
Sites with impulsive interference	7	4	55.0	56.0	3.5**	3.5**
Sites with co-channel interference	2	none	not tested	—	5 to 6	—
City sites. Combined interference	14	4	56.0	56.0	5.5	5.5

* The EBU Impairment Scale

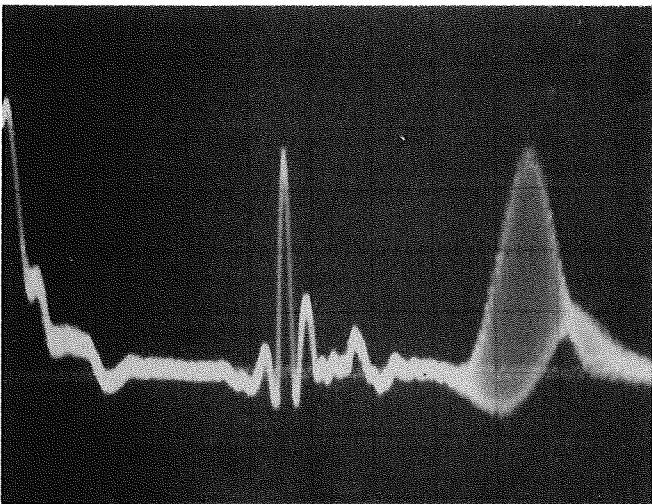
Grade Impairment

- 1 Imperceptible
- 2 Just perceptible
- 3 Definitely perceptible but not disturbing
- 4 Somewhat objectionable
- 5 Definitely objectionable
- 6 Picture unuseable

** The levels of impulsive interference were low and CEEFAX reception failed mainly because of low field-strength.



(a)



(b)

Fig. 4 - I.T.S. 2T and 10T pulse waveforms at two different sites with multipath interference

(a) CEEFAX reception successful (b) CEEFAX reception failed

corresponding figures for the limiting field-strength may be taken conservatively as 54 dB ($\mu\text{V}/\text{m}$) with a corresponding margin of 11 dB.

It was of interest to note that when CEEFAX reception failed due to a site with too low a field-strength from the Crystal Palace transmitter, the distance of the site from Crystal Palace was so great that the mobile laboratory was well within the service area of another transmitter. It was often found on these occasions that the field-strength of the nearby transmitter was from 70 to 90 dB ($\mu\text{V}/\text{m}$): there is, therefore, a considerable overlap of the CEEFAX service areas when field-strength is the limiting factor.

For sites with multipath interference, the margin was found to be reduced to some 5 dB. However, the subjective grade of the interference to the television picture at

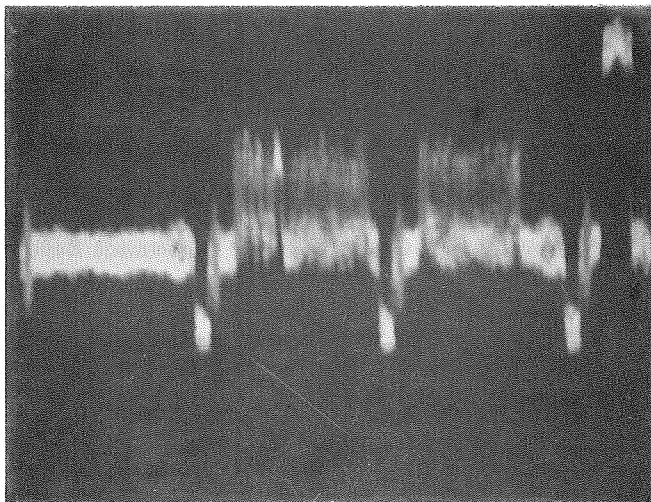
sites where CEEFAX was just received was between 5 and 6 ('definitely objectionable' and 'picture unuseable'). The relative signal level of echoes received in locations where multipath problems were serious averaged 15%. Fig. 4(a) and 4(b) show photographs of the I.T.S. signal waveforms at two sites, at one of which the CEEFAX reception was successful and at the other reception just failed, respectively. Twelve sites were found where CEEFAX reception failed, and echo levels were up to 70% relative to the main signal. At all these sites, colour television reception also either failed or was not viewable, due to picture synchronising or colour-lock problems. CEEFAX reception failed at some sites with the echo-level at about 25%. Both laboratory and site tests showed that CEEFAX reception was vulnerable to severe attenuation or phase distortion of the clock-run-up waveform. This would be produced where one echo or echoes occurred delayed by integer multiples of one-half a clock period. Some sites tested gave this effect — it is similar to the 'notching' of the colour sub-carrier that occurs at some sites and in general relatively small repositioning of the receiving aerial effects a cure.

The effect of impulsive interference was typically to remove a row or group of rows of characters from the received page. In general the levels of impulsive interference that were encountered were small, and reception failed mainly because of random noise interference due to low field-strength. For impulsive interference to cause CEEFAX to break down, the timing of the CEEFAX data-line and any interference pulses must be coincident and, statistically, this is of low probability (1 in 150).

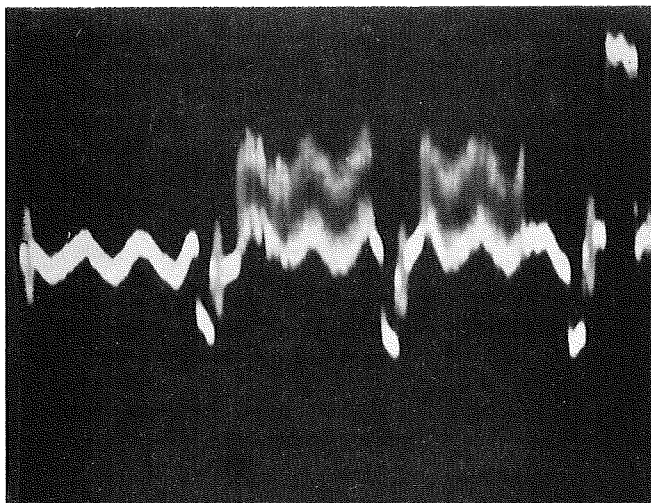
Because of its sporadic nature only one receiving site could be found with co-channel interference, in which the level of interference could be regulated as explained in Appendix II. Photographs of the CEEFAX data waveform were taken and the level of interference adjusted until reception of data failed. Fig. 5(b) shows the result and the level of co-channel interference was 26 dB (wanted to unwanted power ratio). The frequency of the interference shown is about $10/3$ of television line frequency. Fig. 5(a) shows the level of interference of 28 dB (wanted to unwanted power ratio).

In each case the overall subjective grading on the colour picture was between 5 and 6. It was not possible to obtain results of the limiting field-strength at the site with co-channel interference but the photographs indicate that when the data eye-height* is reduced to zero by a combination of co-channel and random-noise interference, CEEFAX reception will fail. It is also clear that CEEFAX does not exhibit any peculiarities of performance in the presence of co-channel interferences. (Since these tests, a decoding technique has been devised to reduce considerably the effects of co-channel interference on data reception and signals with severe co-channel interference at about 20 dB can now be successfully received.)

* 'Eye-height' is the term used to denote the range of discrimination between the data '0' and '1' pulses. Distortion and interference serve to reduce this range and ultimately it is no longer possible to distinguish between a transmitted '0' or '1'. Reception of the data then breaks down.



(a)



(b)

Fig. 5 - CEEFAX data waveform at 4.5 MBits/s with different levels of co-channel interference

(a) CEEFAX reception successful (b) CEEFAX reception failed

At sites in the built-up area of London it was found that CEEFAX reception was not limited by interference. Sites could be found where signal reflections from large buildings did interfere with CEEFAX but, in general, in any given situation, better siting of the aerial was possible and CEEFAX received successfully.

When consideration is given to reception of CEEFAX signals at more remote parts of the television network, the effects of additional distortion must be taken into account. A full investigation into the performance of the network and transmitters was too large to be undertaken at this stage but the following facts have emerged from a short series of supplementary measurements in which the mobile laboratory travelled as far north as Aberdeen.

- (i) The network distortions, as found, were not as serious as the existing maintenance limits might be expected to permit; the worst signal found required a field-strength greater than 60 dB ($\mu\text{V}/\text{m}$) to avoid breakdown of CEEFAX reception.
- (ii) Many of the main transmitting stations cause a small but significant amount of pulse-distortion, correction of the distortion would further improve the CEEFAX service area.
- (iii) With one or two exceptions, the relay transmitters measured caused little or no distortion of the main station feeding them.
- (iv) Rebroadcast stand by operation, in which several main transmitting stations operate in cascade in an emergency, resulted in very poor CEEFAX performance.

It is thought that the encouraging findings of the survey in the Crystal Palace area indicate that similar results would be obtained in other service areas if CEEFAX data-regenerators were placed at selected points in the network; these would remove all distortion from 'upstream' equipment and, if they were placed in the video input circuit of main transmitters, would permit RBS operation to take place without affecting CEEFAX at all. Further, as future RBL cascading of main transmitters is planned for Northern Scotland, it is likely that CEEFAX operation would be seriously impaired without the use of data-regenerators at these stations.

6. Conclusions

An extensive series of field trials has been conducted in the south-east of England on the reception of CEEFAX. It was found that, in terms of field-strength, the service area for CEEFAX was appreciably larger than that for colour television; the field-strength corresponding to the limit of reception at the data rate of 6.875 MBits/s, was 56 dB ($\mu\text{V}/\text{m}$). Since the trials were completed signals according to the new unified data system⁵ have been transmitted. These have an increased data signal level and the slightly higher data-rate of 6.9375 MBits/s. The corresponding field-strength requirement may be taken conservatively as 54 dB ($\mu\text{V}/\text{m}$); this corresponds to a margin of 11 dB over that of the colour television service area. At reception sites where severe multipath interference was also a problem, the 11 dB margin was reduced to about 5 dB.

No special problems concerning the CEEFAX system were encountered. The behaviour of the receivers in conditions of impulsive interference or co-channel interference was largely as expected. A small but not insignificant problem with the group-delay response of transmitters and u.h.f. receivers was, however, identified, and an investigation into the importance of this effect is the subject of separate work.

CEEFAX is a rugged data system and, in general,

wherever colour television is being received with impaired pictures better than grade 5 ('definitely objectionable') CEEFAX reception should be successful.

7. References

1. CEEFAX revised experimental system parameters. BBC Research Department Technical Memorandum No. PH-1111.
2. Specification of television standards for information transmission by digitally-coded signal in the field-blanking interval. Published jointly by BBC, IBA and BREMA, 1974.
3. LE COUTEUR, G.M. Interference due to data transmitted after the television field synchronising signal. BBC Research Department Report No. 1973/12.
4. LE COUTEUR, G.M. CEEFAX: interference with television from data signals transmitted in the field-blanking period. BBC Research Department Report No. 1974/10.
5. CEEFAX: tests on three possible choices of secondary code. BBC Research Department Report in course of preparation.

Appendix I

Aerial System used in the Mobile Laboratory

It was important that the aerial installation in the mobile laboratory was representative of a typical fringe-area domestic installation in both gain and directivity. Under advice from Service Planning Section and BBC Engineering Information Department Sheet 4006(1), March 1970, the relevant features of a domestic installation are as follows:

Aerial gain	14 dB
Feeder loss	4 dB
Receiver noise factor	10 dB

For practical reasons the aerial used in the mobile laboratory was a log-periodic type which had a lower gain than that required. To compensate for this, a low-noise u.h.f. pre-amplifier and u.h.f. attenuator were used, and arranged to give the same output signal-to-noise ratio for a given field-strength as in the domestic installation. In the mobile laboratory the details were:

Aerial gain	8.5 dB
Feeder loss	2.5 dB
UHF attenuator setting	1.0 dB
Pre-amplifier noise factor	5.0 dB
Pre-amplifier gain	13.0 dB

Fig. 6 gives the arrangement of the equipment, and the relative u.h.f. signal levels in each case.

The directivity of the log-periodic aerial complies with that recommended by the CCIR.* It must be remem-

* Directivity template, CCIR XIIth Plenary Assembly. New Delhi 1970, Vol. V Part 2, Rec. 419 and Rep. 122-1.

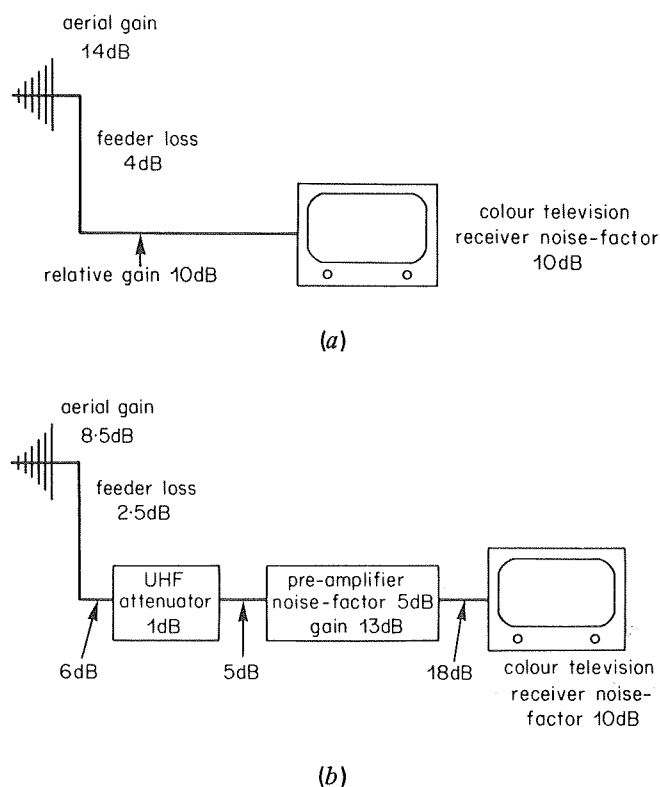


Fig. 6 - Mobile laboratory aerial installation
(a) Typical fringe area domestic installation
(b) Mobile laboratory equivalent arrangements

bered, however, that local reception effects such as influence of trees, buildings, and signal pick-up on the feeder often made the effective directivity of the aerial system depart from that recommended.

Appendix II

Since co-channel interference at a given reception site depends on propagation conditions which are in turn determined mainly by the weather, it was not possible to find a site with significant interference in the ordinary way. A method was therefore devised in the mobile laboratory where controlled co-channel interference could be obtained. It was found that Wrotham Hill lies on a straight line joining the Tunbridge Wells and Sudbury transmitters both of which transmit on Channel 44. Because of the height of the Wrotham Hill site, it was also nearly line-of-sight to the two transmitters. A double aerial system was used

(aerials back-to-back) with a vertically-polarised aerial directed at Tunbridge Wells and a horizontally-polarised aerial directed at Sudbury. An attenuator was placed in series with the feed of the Sudbury signal and the signal at the output of the attenuator was added to the signal at the output of the feed from Tunbridge Wells. In this way the level of the Sudbury signal could be varied and the level of co-channel interference regulated. Tests were made to determine at what relative level the co-channel interference would interfere with CEEFAX reception and the results are described in Section 5.

